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THE OCCURRENCE AND PREVENTION OF FRAZIL ICE BLOCKAGE AT WATER SUPPLY INTAKES

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THE OCCURRENCE AND PREVENTION
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FRAZIL ICE BLOCKAGE
AT
WATER SUPPLY INTAKES

A LITERATURE REVIEW AND FIELD SURVEY

By

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ABSTRACT

A review of research on the properties and behaviour of frazil ice and a field survey of frazil ice experiences at water works in Ontario has been made. Various methods that have been used to alleviate ice troubles have also been reviewed.

The greater number of surface water supply installations surveyed have not experienced any ice troubles. Forty installations, representing about 22 percent of those surveyed, have experienced frazil ice problems on one or two occasions, and at seven installations frazil ice is a source of trouble nearly every winter.

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1.0 INTRODUCTION

One of the difficulties encountered in the operation of water works in Ontario results from the clogging of the water intake system by anchor ice and frazil ice. Frazil ice particles commonly appear as needle-like fragments which form near the surface in turbulent, open water, and, because they have little buoyancy, are readily carried below the surface by comparatively weak currents. When the ice particles are carried into an intake they obstruct the flow by adhering to the trash racks or screens. Anchor ice behaves like frazil ice but it forms directly on submerged objects in shallow, open water due to excessive heat radiation and adds to any frazil ice accumulations. To prevent operational problems due to ice it is therefore necessary to locate and design water intakes such that the possibility of interruption of the supply will be minimized.

Each year, during the winter months, the Ministry of the Environment receives requests from water works authorities for assistance in solving ice blockage problems. This report has been prepared to provide information to consultants and water suppliers and to the Ministry on action to take when trouble is experienced, and also to aid in the design of new intakes with respect to ice problems. The report includes a review of research on frazil ice and a survey of experiences

at water plants in Ontario. In addition, various methods that have been used to alleviate ice troubles have been reviewed.

2.0 FORMATION OF ICE

During the fall in a fresh water lake when the surface water, cooled by contact with the cold air, reaches a temperature in the order of 6 to 7°C, normal wind-stirring and wave action is sufficient to completely mix the water mass of the lake from top to bottom and the lake approaches isothermal conditions. This condition is maintained until all the water in the lake has cooled to about 4°C, the temperature of maximum density of water. On continued cooling where there is very little wind, the cold water will remain in the surface layer and its temperature will decrease to 0°C. If the water remains undisturbed and the cooling continues, a continuous sheet of ice forms. Once the surface is frozen over the ice cover acts as a heat insulating layer significantly reducing the cooling effect of the air and this usually prevents the formation of frazil ice. (1-3)

If the water is disturbed however, as in a fast flowing river or on the surface of a lake stirred by wind, surface water cooled by contact with the cold air is mixed with bottom water so that the entire mass of water becomes colder than 4°C. As the cooling continues, surface water becomes supercooled and ice crystals in the shape of discoids and spicules begin to form, but owing to the turbulent mixing of the water there is no opportunity for these crystals to stick together to form an ice sheet. As growth proceeds, dendrites grow out from these

crystals to form needle-like particles called frazil ice. Because they have little buoyancy the frazil ice particles are readily distributed throughout the body of water depending on the degree of turbulence. Under favourable cooling conditions these particles rapidly form and agglomerate into large spongy masses sometimes termed 'slush' ice and when large quantities of slush ice or frazil ice are carried into an intake they may cause an obstruction to the flow of water by adhering to the intake screens or crib structure and gradually closing off the port openings. (1, 4)

If a submerged type intake is located in shallow, open water where frazil ice is forming, ice may also crystallize and grow directly on the surfaces of the intake structure and add to any frazil ice accumulations. This is commonly known as anchor ice and it is usually formed at night in clear cold weather or on cloudy days. (5,6) Anchor ice does not normally form at depths of 40 to 45 feet or more though this depends on the turbidity of the water. (7)

3.0 FORECASTING FRAZIL ICE FORMATION PERIODS

Research on the properties of frazil ice indicates there is a good correlation between the nature and quantity of ice produced and the rate of cooling of the water within a critical temperature range. When the rate of cooling is greater than 0.01 C^{O} per hour down through $0^{O}C$, frazil ice forms. As the amount of supercooling increases, the amount of frazil ice produced increases and its adhesiveness intensifies. At cooling rates less than 0.01C^{O} per hour, which normally occur only in calm, cold weather, a natural sheet of ice forms. (4, 8, 9)

The loss of heat from a water surface is dependent upon a number of factors including the degree of mixing, amount of surface ice, and certain atmospheric conditions, such as air temperature, wind conditions, amount of precipitation, etc. (4, 10,11) Reporting on ice troubles in Lake Michigan, Baylis and Gerstein (12) indicated that, "frazil ice formed under a wide variety of wind and air temperature conditions. Ice formations usually occurred in the late-evening or early-morning hours and rarely lasted until noon". It is very unusual for frazil ice to form when the sun is shining or when the sky is clouded at night. Ruths (3) reports that, "with a cold north wind and clear weather, frazil ice formation has been observed in river water at a temperature of a few degrees below $0^{O}C$ while no such formation has been observed in cloudy weather under otherwise similar conditions.

With air temperatures as low as $-25^{\circ}C$ or $-35^{\circ}C$ and no wind, frazil ice will not always appear owing to the presence of a heat insulating layer of moisture saturated air on top of the water which will prevent the cold air from cooling the surface water to the critical temperature".

These reports indicate that conditions conducive to the formation of frazil ice vary considerably at a particular site. It appears that the use of meteorological data to forecast frazil ice formation is questionable.

At one power plant installation, intake water temperature data is used to detect conditions that are conducive to the formation of frazil ice and thereby indicate to the operator when remedial measures should be taken. (8) Whenever the data indicates a drop in temperature greater than 0.01 C° per hour below $0.1^{\circ}C$, the intake screen heaters are turned on. When the temperature rises above the range where frazil ice forms heating is discontinued. Following this procedure has made it possible to completely avoid ice blockage problems at the intake structure. (13)

Williams (4) points out at least one difficulty to be overcome by anyone contemplating the continuous measurement of water temperature near $0^{\circ}C$. He indicates that as soon as the water temperature falls below freezing, ice begins to form on the temperature indicator and the only temperature then recorded is the freezing point. To overcome this, provision should be made for melting the ice on the indicator after each ice run.

4.0 GROWTH AND ADHESION OF FRAZIL ICE

The main problem with frazil ice is created by the tendency of the ice particles to adhere to each other after formation or to adhere to submerged objects in supercooled water. Research on the properties of frazil ice has shown that the thermal properties of materials affect the rate at which ice will adhere to and grow on them in supercooled water. Williams (9) indicates that the rate of ice growth is enhanced on a metal surface, because the metal, with good thermal conductivity, acts as a heat sink for the removal of the latent heat released when ice starts to form on the surface. Ice does not crystallize and grow as rapidly on a wood or plastic structure, suspended in supercooled water under similar conditions. In addition, factors such as the degree of turbulence of the supercooled water, amount of supercooling, or shape of the underwater structure, can affect the rate at which latent heat is removed. Under laboratory conditions and supercooling to $-0.1^{\circ}C$, Williams observed frazil ice will adhere to steel but not to plastic or plastic-coated steel. If, however, the amount of supercooling is increased to $-0.2^{\circ}C$ or the period of supercooling is prolonged, ice was observed to adhere to plastic and plastic-coated steel although in lesser amounts than to untreated steel. (9)

It is also indicated that surface properties may have a significant influence on the ability of an adhesive bond to be formed between ice carried by the flowing water and an

underwater structure. While acknowledging that it is difficult to separate surface effects from thermal effects, Williams indicates that ice does not appear to adhere as readily to a smooth, plastic finish as to unprotected steel. (9, 14).

5.0 DESIGN CONSIDERATIONS

The greater number of water plant intakes used throughout Ontario are submerged intakes which normally consist of a protective intake screen, or crib structure, located over the inlet and through which the water enters the system, and a bell mouth pipe inlet connected to the intake conduit which conveys the water by gravity or suction to the shore facilities. Some of the smaller municipalities do not use a protective crib but are supplied through a submerged pipe intake buried in the bottom of the body of water and having an elbow that is turned upward with the opening protected by a metal screen to prevent foreign objects from entering the inlet.

Measures can be taken in the design and location of submerged crib type intake structures that will reduce the frequency and intensity of ice troubles. Experience at water works intakes in the Great Lakes has shown that, if the velocity of water where it enters the crib openings (port) is maintained below 0.3 feet per second (fps) during winter operation and the intake structure is located at a water depth of 45 feet or more, the amount of surface formed ice carried down to the inlet by the intake current is minimized. (5, 17-20)

Depending on local conditions, deep submergence and low port velocities may not necessarily prevent the accumulation of ice

on the intake structure. Large quantities of surface-formed ice and ice producing (supercooled) water may be carried down to the intake structure because of mixing due to wind and wave action. To reduce the probability of this surface-formed ice adhering to the intake structure, and to inhibit the formation and growth of ice on the exposed surfaces, the structure should be constructed of materials that have low heat transfer properties and smooth surface properties. (4, 14,17)

Perhaps the first water intake screen, or crib specifically designed and fabricated using special materials to protect against ice problems recently became operational for the City of Hamilton Water Treatment Plant. Fiber glass reinforced plastic was specified for the protective intake structure because the material's low thermal conductivity and smooth surface, which inhibit frazil ice formation, offered maximum protection against ice blockage. In addition, compared to other materials considered which included wood, stainless steel, wrought iron, bronze and coated ferrous metal, fiber glass reinforced plastic proved competitive in cost, light in weight, chemically inert, and provided a minimum obstructed area. (15,16)

In the design of the intake structure, consideration should be given to its hydraulic characteristics, which reportedly may influence the formation and accumulation of ice within the intake (14, 17) Michel (21) has observed that frazil ice does not form if the flow is laminar. Pariset and Hausser, (22)

while conducting tests in conduit pipes of the City of Montreal Water Intake, observed that frazil ice deposits appeared only in the disturbed flow areas. To discourage the formation of frazil ice within the intake, Richardson (17) indicates that the intake structure should be designed with a minimum number of obstructions to the free flow of water and, the system should be hydraulically balanced to draw from the largest volume of water practicable and to maintain a uniform water acceleration through the ports and into the inlet opening.

6.0 METHODS OF OVERCOMING FRAZIL ICE TROUBLES

Compressed air, back-flushing and light explosives (¼ lb. of 60% dynamite) have been used to remove ice from submerged intake ports. (20) Compressed air, heated water, or steam, discharged into the water at the intake structure through perforated pipe reportedly have been effective in removing ice from the crib openings. Back-flushing through the ports can be done by draining an elevated storage tank into the intake conduit or discharging the flow from the main pumps into it, the pumps drawing their water from storage on the distribution system. (6) Reports of remedial measures employed at one intake indicated that back-flushing proved satisfactory about one out of five attempts; for the rest of the time more water was wasted than came in through the intake before it was again clogged. (23)

The accumulation of ice on the intake structure can be reduced or eliminated by heating the exposed surfaces or raising slightly the temperature of the incoming water. Studies have shown that the ability of frazil ice particles to adhere to foreign objects in water depends on whether the ice is growing or melting. (11, 21) If the water entering an intake is heated to increase its temperature a few hundreds of a degree above the bulk water temperature, thereby starting a melting of the frazil ice, its ability to adhere to the intake screens, trash racks or other objects can be significantly reduced.

Electrically heating intake screens to prevent ice problems has been successfully applied at several plants. (4,8,13, 24-29). The data available on some of the earlier installations, which based their power requirement for heating screens and trash racks on hydraulic flow, show an energy consumption of from 140 to 425 watts per cubic foot of water per second to raise the temperature of the water entering the intake by from 0.02 to 0.4 C^{o} above the bulk water temperature. (3, 8, 24, 29) Although these installations were reported as working satisfactorily, (24) it has been indicated that for large installations, the quantity of water used is so great that it is considered practically impossible to supply enough heat to the racks to raise the water temperature a sufficient amount. (13, 24)

Heating the intake screens by circulating steam or hot liquids through pipes inserted into the bars of the screen has been tried. (3, 24) This method, however, is very elaborate and generally has not proved satisfactory. Its thermal efficiency makes this method very uneconomical and it should not be considered for water plants except in locations where low cost energy is readily available. (24)

Very good results have been obtained at power plant intakes designed to prevent the accumulation of ice on the screens by raising the temperature of the exposed surfaces rather than heating the incoming water which may require up to 6 times more energy. (11) Ruths (3) indicates that if the temperature

of an object such as the bar of an intake screen is raised above the critical temperature to between 0.06° and 0.1° C, frazil ice will not adhere to the bar, facilitating the ice passing through the structure and its accumulation in the pump suction well or other more accessible area. At one power plant intake installation which is located in Lake Ontario, heater elements were installed in each bar of the screen to maintain a metal surface temperature 2 F° ($1C^{\circ}$) above the bulk water temperature to prevent the accumulation of ice on the bars. To further reduce the possibility of adherence of ice and to increase radiation heat gain, the heating rack was sprayed with a smooth, black, coal tar epoxy coating. (13) This system, designed with an intake velocity of 0.8 fps and located in 31 feet of water, has operated successfully without an icing problem since 1968. As far as is known, electrically heating intake screens to prevent the accumulation of frazil ice has never been done on an operational basis at a water works intake.

Experiences at power plants have shown that ice covers immediately upstream of water intakes reduce greatly and sometimes even eliminate the troubles caused by frazil ice. (3, 7, 11, 26, 29) A continuous sheet of ice stops the generation of frazil and anchor ice and, although an ice cover may not prevent ice that is formed in open water from being carried below the cover by the flowing water and entering a water intake, it appears to influence the adhesive ability of the ice. It has been indicated that the adhesiveness of ice particles depends on the state of the crystals.

Michel (21) indicates that the ability of frazil ice to adhere to foreign objects occurs only during its period of formation. Reporting on work by Gale, Williams (4) indicates that freshly formed frazil ice is very adhesive and much more difficult to handle than that which has passed under surface ice. It has been shown that the temperature of moving water tends to increase as the flow progresses under an ice cover (11); as frazil ice travels under a cover, the ice particles would start to melt thus reducing their ability to adhere to screens, trash racks, or other objects.

Ice troubles in river intakes have been minimized by locating the intake in protected water, such as a lagoon or forebay, where the surface will readily freeze over. A method which has been used successfully in unprotected water which is applicable to intakes located in shallow water at or near the shore of rivers, small lakes, or reservoirs, is to create a quiet body of water over the intake by means of a raft or boom of logs thereby facilitating the formation of an ice sheet. (5)

7.0 SURVEY OF EXISTING WATER SUPPLY INSTALLATIONS

Based on reports received by the Ministry, the frequency and intensity of ice blockage problems varies between plants and from year to year. On a number of occasions icing problems have resulted in interruptions in the supply. Also, while these problems are experienced at a particular plant, in several instances an adjacent plant that is subject to many similar conditions does not experience a problem with ice.

To obtain the information used in this section, questionnaire forms were mailed to 146 public surface water supply authorities and 38 operators of industrial and/or private surface water supply systems. Those surveyed were requested to indicate on the form if they have experienced frazil ice problems, complete the form as fully as possible, and return the form to the Research Branch.

Replies were received from about 70 percent (129) of those surveyed; some respondents forwarded drawings and related information in addition to completing the questionnaire forms. Completed forms were received from about 80 percent (106) of the respondents. The other forms received (23) were incomplete and were not used for this study.

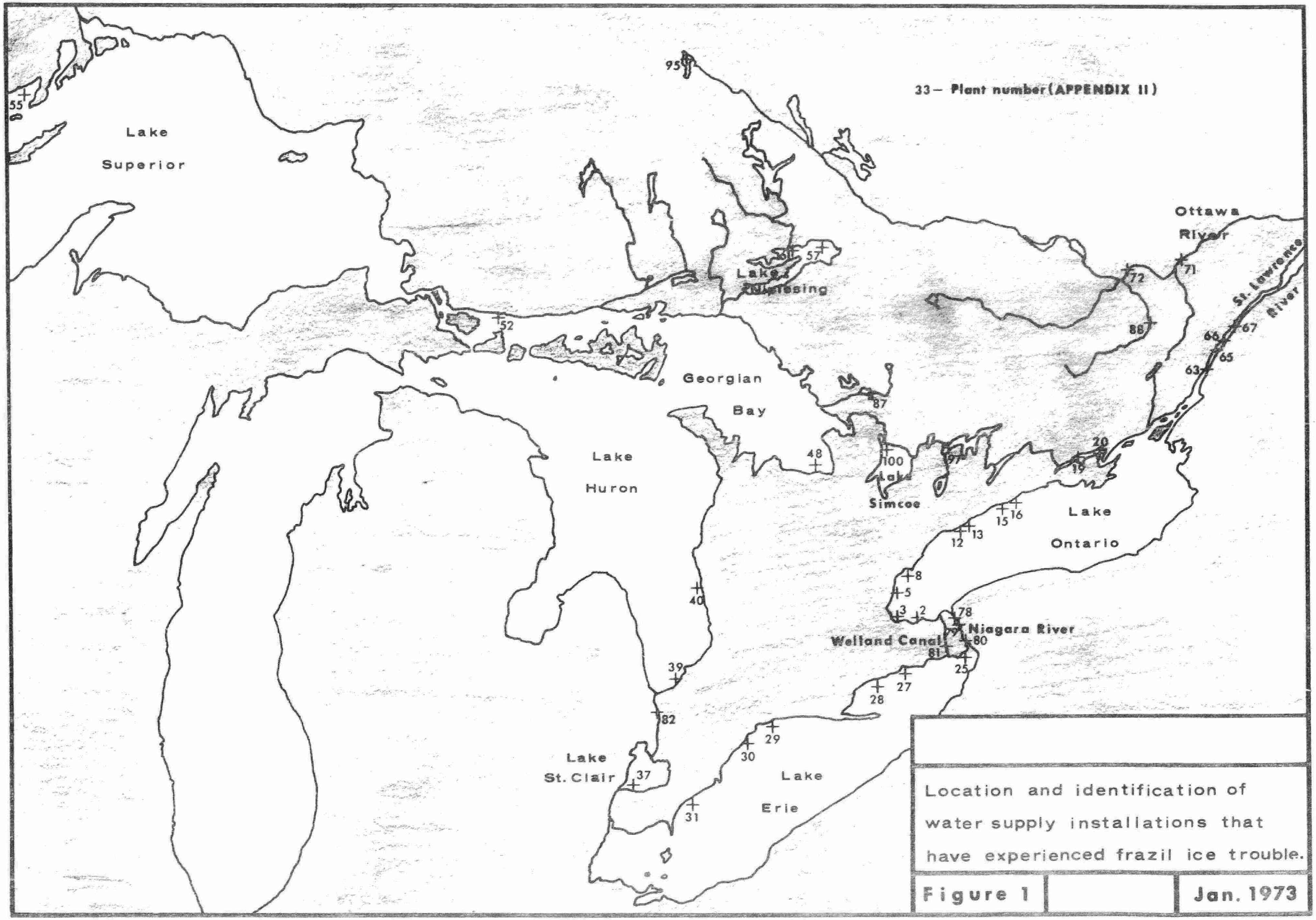
The summary of information obtained from the survey is given in Appendix I. Where applicable the year(s) a problem was experienced is indicated.

The general design data of the installations are compared in Appendix II. It will be noted that the installations are classified according to supply source and listed by location. A positive (+) notation has been made to indicate a particular installation which has experienced ice blockage problems.

Forty respondents, representing about 22 percent of the installations surveyed, indicated that they had experienced frazil ice problems on one or more occasions; these installations are located on a number of lakes, rivers and canals throughout Ontario (Figure 1). About 5 percent (7) of those surveyed indicated that frazil ice problems occur practically every winter. In the majority of cases, ice problems have been experienced only on one occasion.

Icing problems are usually evidenced by excessive draw down in the intake (low lift) wet well. When frazil ice contacts the screens in the wet well, it adheres to them until they are completely clogged. One case is reported where, because of the reduced flow through the screen, the draw down in the wet well resulted in an excessive head across the screen which finally caused it to rupture.

Ice troubles at the shore wet well may be more serious when using fixed or stationary screens because of the difficulty of cleaning them. Several remedies have been tried to keep the screens free of frazil ice. Compressed air or steam injected on the back side of the screen, hand scrapers, and mechanical scrapers of various designs have been used. Another procedure used is to lift the screen partly or remove it when the ice



Location and identification of water supply installations that have experienced frazil ice trouble.

Figure 1 Jan. 1973

troubles start, thus allowing the water and ice to pass through. This practice does entail some risk that other foreign material may enter the wet well.

Screens which can be moved continually upwards and cleaned of ice adhering to them by a stream of water, or steam, are more desirable. Of those installations that experience frazil ice problems, 12 are equipped with travelling screens that are cleaned automatically or manually, 21 are equipped with fixed screens that can be removed when necessary and 5 do not have screens installed in the wet well.

The greater number of icing problems concentrate at the inlet. Frazil ice and slush ice carried by the moving water, together with any anchor ice that forms, accumulate at the inlet works and gradually clog the crib-intake ports so that the crib structure becomes covered with ice. When the shore well screens are not clogged, an increase in the draw down indicates that the flow of water into the inlet is restricted.

About one-half (19) of the installations where frazil ice problems are experienced have some provision for back-flushing through the intake conduit. Seven of these installations are provided with elevated storage tanks or storage reservoirs that can be drained into the intake conduit, 2 apply back pressure using water stored in stand pipes, and 3 use their filter backwash pumps to pump backwash water into the intake conduit. Another method to apply back pressure that has been tried at two installations, is to isolate the intake wet well

and, using water from the treatment plant, to fill it up as high as possible then discharge the water back into the intake conduit. The method(s) used at the other installations to apply back pressure were not indicated. Back-flushing has proved successful at those installations that only occasionally experience ice blockage problems and only when the problem is not severe. In all but one or two cases, for those installations that experience severe ice problems over prolonged periods, none of these methods for back-flushing have proved very satisfactory.

Some attempts have been made to float the accumulated ice away from the crib structure using compressed air. This may be done by closing the gate between the intake conduit and the wet well and discharging air under pressure into the conduit. This method may require a large volume of air depending on the size of the intake conduit, is time consuming, and has usually been unsuccessful. At two installations divers have been employed to scrape ice off the crib to allow the passage of water. This is a dangerous practice and is not encouraged.

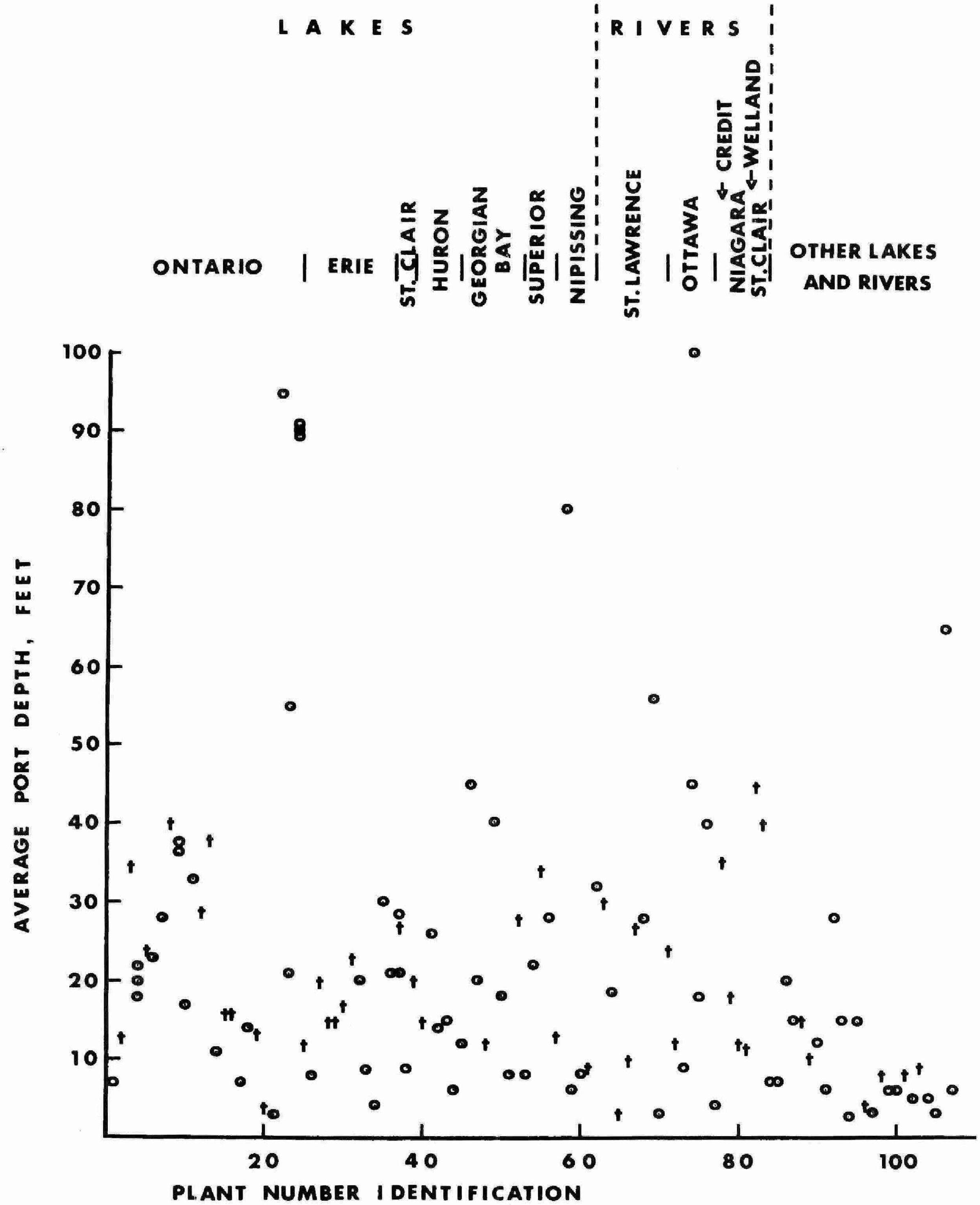
Another procedure that has been used to remove ice adhering to the crib, involves throttling the intake well pump(s) to control the draw down and thus maintain some flow through the intake. In this way it has sometimes been possible to erode the ice bridging the crib-intake ports and thereby restore the flow. This method of controlled draw down has proved to work satisfactorily and in many instances is preferred to back-washing which represents the waste of significant volumes of water.

7.1 General Design Data

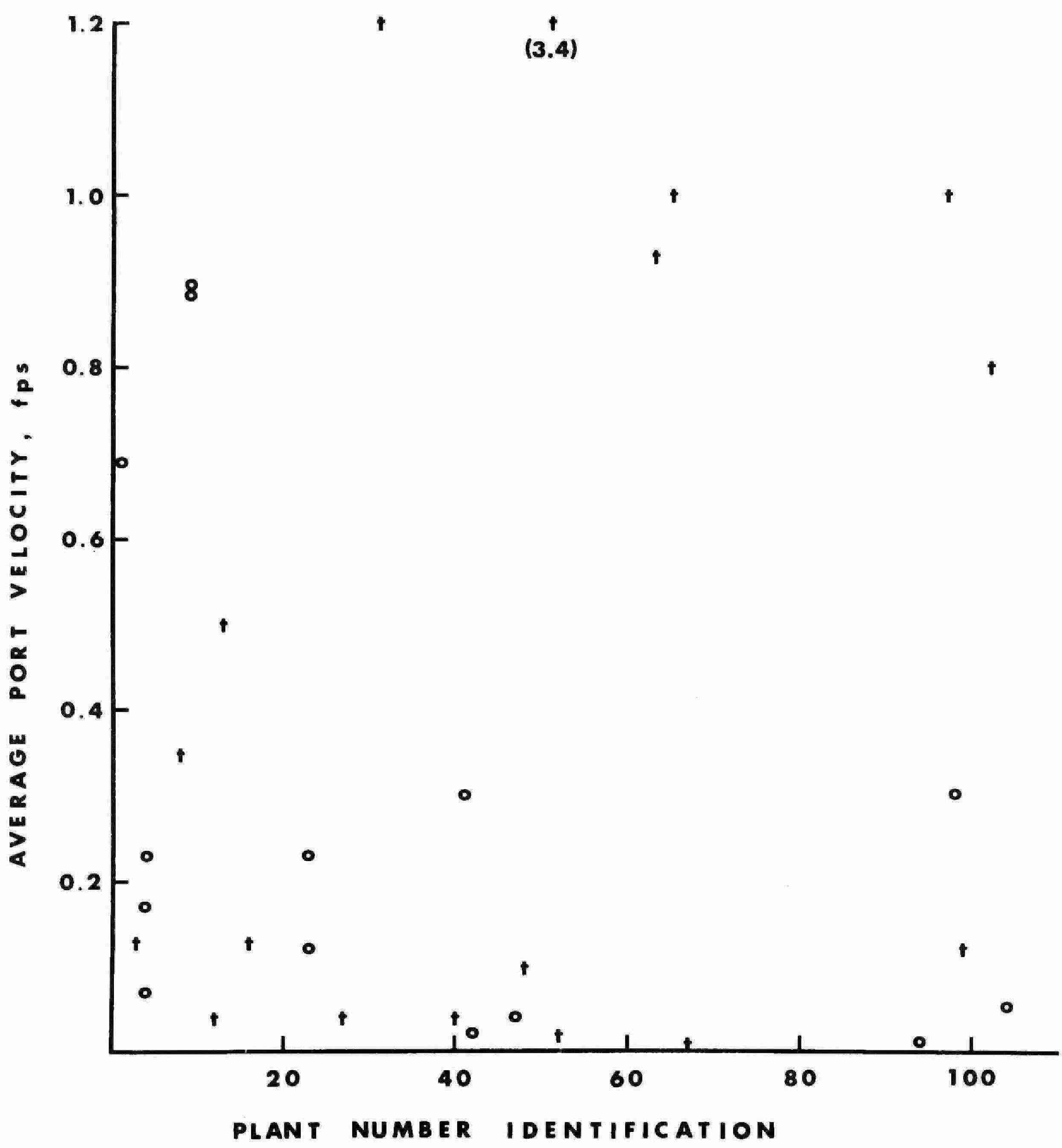
It has been indicated that while some installations experience frazil ice problems, adjacent installations that are subject to many similar conditions do not experience ice problems. For example, on numerous occasions during the past eight winters, 9 water supply installations located along the shore of Lake Ontario that use submerged crib type intakes have experienced frazil ice problems; ten other installations located along the shore of Lake Ontario with similar intakes have not experienced any frazil ice problems. The average daily flows, sizes, water depths, intake locations, and port velocities of the various water supply intakes are tabulated in Appendix II.

Examination of the general design data for these installations does not indicate any apparent differences in the respective intake structures that could account for the occurrence of frazil ice formations at a particular installation. Ice problems have occurred between depths of 3 and 40 feet; installations with depths of 2.5 to 100 feet have not reported icing (Figure 2). It appears that the minimum depth at which ice troubles will not occur probably depends greatly on local conditions.

To reduce the probability of surface formed ice being carried down to the inlet by the intake current, submerged intake cribs used in the Great Lakes historically have been designed with sufficient open area so that the velocity of flow through



Summary of frazil ice occurrences at water supply installations showing average port depth.		
Figure 2	avmg	JAN. 1973



Summary of frazil ice experiences at water supply installations showing average port velocity.		
Figure 3	avmg	JAN. 1973

the ports will be maintained below 0.3 - 0.5 fps during winter operation. From the data shown in Figure 3, referring to crib structures located in Lake Ontario, ice trouble has occurred at installations with port velocities varying from 0.04 to 0.50 fps while icing has not occurred at installations with port velocities ranging from 0.07 to 0.89 fps.

There are no notable differences in the general design data between the various intake structures that are located in other lakes and rivers throughout Ontario (Figures 1 and 2). These results imply that general local conditions probably have the most significant influence on the development of conditions that are conducive to the formation of frazil ice. The design and location of the inlet structure probably have influenced the frequency and severity of ice problems experienced at most of these installations, although they may not necessarily completely eliminate the accumulation of ice at the intake.

7.2 Conditions Prevailing During Frazil Ice Formation Periods

From an examination of the reports that were received it was found that conditions prevailing during frazil ice formation periods vary considerably at different sites. Generally, ice blockage problems occur in the night and rarely last until mid-day, except if the sky is overcast. During frazil ice periods, water over the intake usually is open or covered partly with surface ice or slush and, in several instances, snow or freezing rain was falling over the water.

Some operators have reported that once the water temperature is below 1^{o} - $2^{o}C$, severe frazil ice formations may occur whenever there is a rapid decrease in air temperature to a range of -7^{o} to $-15^{o}C$. Experience at an industrial water supply intake in the city of Cardinal indicate that conditions existing when there is a large temperature change in a short period of time are more conducive to the formation of frazil ice than during a prolonged period of very cold weather where the mean air temperature does not vary 3 C^{o} in 24 hours.

At one installation, frazil ice problems are sometimes experienced when there is a sudden change in air temperature and wind direction with the wind blowing against the downflow current and a clear sky overhead. Most installations located on smaller lakes reported ice problems usually occur in early and late winter when surface ice is forming or breaking up and the water over the intake is covered partly with floating ice. Under these conditions, the major blockage problems resulted from wind-blown ice piling up over the intake.

The problem at another installation appeared to be a combination of wind-blown ice piling up over the intake and frazil ice formation around the intake opening. The result was a severe reduction in water flow and eventually complete blockage of the intake opening. At the same time frazil ice also accumulated around the screens at the intake well. As is the case at the vast majority of the installations that have experienced frazil ice troubles, ice problems have occurred only once and may not recur.

Several installations with intakes located in protected water experience ice problems during early winter. Once the water surface is frozen over, additional ice problems are not encountered. In many cases, ice problems experienced at river intakes occur during spring break-up and thawing weather when floating ice packs jam in the river causing blockage or partial blockage in the intake. Problems with ice jamming were reduced at one installation after an ice boom was installed to protect the water surface above the intake.

At another installation, the only problem with frazil ice occurred under unusual circumstances when the pumping rate was necessarily increased to more than double the average daily winter flow. At the time when the problem was experienced, the air temperature was -30° to -26° C, there was no wind, and the river was calm and ice covered with open areas. With the high intake flow, surface formed ice was probably drawn into the inlet by the intake current. The intake well screens iced over and the accumulated ice completely blocked the flow.

8.0 SUMMARY AND CONCLUSIONS

An analysis of the different reports submitted by the operators of 88 public and 18 industrial and/or private surface water supply installations indicates that the greater number of plants have not experienced any ice troubles. In the majority of plants where ice troubles have occurred, problems have been experienced on only one or two occasions. Frazil ice is a source of trouble at seven installations nearly every winter and it may reduce partially the quantity of water passing through the intake and at times totally obstruct the flow. This problem is not restricted to one supply source.

Experience indicates that submerged crib type intakes can be located to reduce the frequency and severity of ice troubles. If the inlet ports can be located at a water depth of 45 feet or more and if port velocities can be maintained below 0.3 fps during winter operation, this will reduce the probability of surface formed ice being carried down to the inlet by the intake current.

Protective crib structures, trash racks and inlet screens should be constructed of materials such as wood and fibreglass because their low heat transfer properties affect the rate at which ice will adhere to and grow on their surfaces. Exposed metal surfaces in the water supply intake system should be coated with some inert material, such as black epoxy paint, to effect better thermal properties and to increase radiation heat gain.

Reports indicate that frazil and anchor ice formation periods in flowing rivers and lakes stirred by wind may last from several hours up to eight to ten days under prolonged, severe, cooling conditions. (3) (4) (14) Under these circumstances, Williams (14) cautions that there may be no significant difference between the amount of ice that will accumulate on a metal structure and a plastic-coated metal, plastic or wood structure which have better thermal properties. The City of Hamilton Water Treatment Plant crib intake structure was perhaps the first such installation constructed using special materials with low heat transfer properties to protect against ice troubles. An ice blockage problem was experienced at the intake during the first full winter of operation, however, indicating that the use of special materials will not necessarily eliminate ice troubles.

When the intake ports are clogged with ice, most operators apply back pressure to remove the adhering ice; provision for back-flushing should be made when the installation is constructed. When an ice formation period is prolonged, experience has shown that the method of controlled draw down is preferred to back-flushing.

Heated intake screens have been used successfully at several power plant installations and may be an effective method of reducing ice blockage problems at water plant intakes. In the case of frazil and slush ice being carried down to a submerged intake, heating and screens or trash racks would not necessarily prevent ice jamming at the structure, particularly if large quantities of ice are drawn to the intake. Reid (24)

indicates electric heating of racks is of particular value in locations where frazil ice trouble develops quickly and where it is not of long duration. For most installations, it may be difficult to justify the investment required to provide electrically heated intake screens especially where ice blockage problems have been experienced on only one or two occasions. Based on cost data available for existing power plant installations, the complete heating system may add 50 to 100 percent to the total cost of the intake structure. (8, 13, 24).

Adequate equipment should be provided for removing ice accumulated at the intake wet well screens. Of those installations experiencing ice troubles nearly every winter, one is equipped with travelling screens, five are equipped with fixed screens, and one installation does not have screens in the intake wet well.

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APPENDIX I

SURVEY OF EXISTING WATER SUPPLY INSTALLATIONS

Installation	Design Capacity (MIGD)	Population Served 10^3	Type of Intake[1]	Water Depth At Intake (Ft.)	Year Ice Problems Experienced
Abitibi Paper Co. Ltd.					
Iroquois Falls	0.5	-	a	16	1967
A.E.C.L. Chalk River	NA	-	a	100	none
		-	a	55	none
Alexandria	1.0	4	a	NA	none
Allied Chemical Ltd.					
Amherstburg	4.0	-	NA	NA	none
Ajax	2.0	NA	a	36	none
Arnprior	3.8	6	a	10.5	none
Bala	0.4	NA	a	9	none
Bancroft	NA	NA	c	23	none
Belle River	2.0	6	NA	NA	none
Belleville	8.0	33	a	19	1965
Bertie Twp.	8.5	21	a	23	none
Bowmanville	2.4	9	a	21	none
B.P. Refinery Canada					
Ltd. Oakville	NA	-	a	31	none
Bracebridge	3	4	c	37	yearly
Brockville	2	21	c	37	1962
Brockville Chemical Ltd					
Maitland	NA	-	a	25	none
Burlington	40)		a	33	none
	7.4)	48	a	27	none
	3.1)		a	25	none
C.F.B.-Hornell Heights	NA	-	a	88	none
-Moosonee	0.3	-	a	14	none
-Trenton	NA	-	a	NA	none
Cache Bay	NA	NA	a	12	none
Canada Starch Co.					
Cardinal	9.8	-	a	27	yearly
C.I.L. Millhaven	NA	-	a	100	none
Carleton Place	2.5	NA	a	15	1968
Chats Falls G.S.					
Fitzroy Harbour	NA	-	b	52	yearly
Cobden	0.06	NA	c	16	none
Cobourg	6.4	12	a	20	1968
Collingwood	6.4	9	a	17	1963,4, 8
Cornwall	15	44	c	13	none
Crystal Beach	1.3	NA	a	16	yearly
Deep River	NA	5	a	34	none
Deseronto	3.3	NA	a	10	1965
Dunn Twp.	2.5	6	a	27.5	yearly
Dupont of Canada Ltd.					
- Kingston	NA	-	a	96	none
		-	a	96	none
		-	a	92	none
- Maitland	NA	-	c	4	1962, 5
- North Bay	NA	-	a	16	yearly
Eganville	0.2	NA	a	8	none
Espanola	1.7	5	a	31	none
Fort Erie	5.6	10	a	14	1966, 7
Freeman	1.2	NA	a	NA	none
Gananoque	4.3	5	NA	42	none
Goderich	1.5	7	a	30	1962,3,4,7,9
Grimsby	3	2	a	NA	1968
Haileybury	NA	3	NA	50	none
Hamilton	120	318	a	42.5	1968
Harrow	1.25	NA	a	27	none
Hearst	NA	3	a	4	none

/continued

APPENDIX I (Cont'd)

Installation	Design Capacity (MIGD)	Population Served 10^3	Type of Intake[1]	Water Depth At Intake (F+)	Year Ice Problems Experienced
Huntsville	1.4	4	a	21	none
Iroquois Falls	1.5	1	NA	48	none
Jarvis	0.18	NA	a	NA	1967-8
Kimberly Clark Co.					
Terrace Bay	NA	-	c	41	1956
Kincardine	1.0	3	a	21	none
Kingston-City	26	70	a	60	none
-Point Pleasant	4.2	NA	a	35	none
Lake Erie System			a	33.5	none
Lakefield	0.3	2	c	NA	none
Lake Huron System	67	NA	a	32	none
Lindsay	6.0	12	c	NA	1968, 9
Little Current	1.5	1	NA	NA	none
Marmora	0.5	NA	c	9	none
Michipicoten	NA	NA	a	38	none
Midland	NA	NA	a	46	none
Morrisburg	1.0	NA	a	63	none
Napanee	1.9	5	a	7	none
Niagara-on-the Lake	1.0	3	a	NA	1965
Niagara Falls	20	60	a	31	NA
North Bay	7.5	46	c	12	none
Oakville	19	49	a	29	1968
Orillia	9	17	a	8	1940
Oshawa	21	78	a	43	1942,68
Ottawa	42	356	c	29	1968
Owen Sound	5	NA	a	85	none
Perth	NA	6	c	14	none
Peterborough	14	54	c	NA	1967, 8
Petrolia	2.8	14	c	23	1968
Pickering Twp.	1.3	17	a	25	none
Port Arthur	NA	NA	a	42	none
Port Carling	0.15	NA	a	10	none
Port Colborne	4.5	18	a	20	none
Port Elgin	1.8	NA	a	19	none
Port Hope	1.3	7	c	18.5	1968
Port McNicoll	0.9	3	NA	20	none
Port Rowan	0.5	NA	c	6	none
Port Stanley	0.75	5	a	30	1954,68
Prescott	2.4	5	a	16	1956
St. Catherines	22	98	b	NA	none
St. Lawrence Starch					
Co. Port Credit	NA	-	a	31	none
Sarnia	24	64	a	55	1968, 9
Sault St. Marie	11.5	NA	c	28	none
Smith Falls	4.2	13	a	8	none
Southampton	2.0	NA	a	11	none
Streetsville	0.9	6	a	NA	none
Sturgeon Falls	1.7	NA	a	12	1969
Sudbury	12.5	84	a	80	none
Thessalon	1.2	2	a	32	1965
Timmins	32	32	b	12	none
Toronto - R.C. Harris	300	NA	a	56	1968
- Westerly	120	NA	a	50	none
	120	NA	a	50	none
Trenton	2.6	15	a	19	none
Union Gas Co.					
Port Alma	0.9	-	c	28	1968
Welland	12	43	b	22	1967
West Lorne	0.7	NA	a	29	NA
Wheatly	1.0	3	a	28	none
Whitby	3.0	15	a	49	1968
Wiarton	1.8	NA	a	16	none
Windsor - Old	NA	NA	a	30	1966
- New	33.7	28	a	40	none
- Techumsch	4.0	NA	a	26	none

Note: 1 a - Submerged crib type intake
b - Shore intake headwall
c - Unprotected intake

APPENDIX II

GENERAL DESIGN DATA

Supply Source								Intake Structure			
									Ports		
Plant Number	Identification Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Construction	Water Depth (ft)	Area (sq.ft)	Average Velocity (Fps)
	Lake Ontario									
1	St. Catherines	-	13	Shore	Intake (2)	7 x 5	Concrete	7	70	0.69
2	Grimsby	+	0.9	743	1.5	NA	Steel, wood	13	NA	NA
3	Hamilton	+	62	3098	8	12	Concrete, fibreglass	34.5	875	0.13
4	Burlington	-	40	2450	5	NA	Steel, wood	18	370	0.23
		-	7.4	2400	2.5	NA	Steel, wood	22	80	0.17
		-	3.1	2350	1.6	NA	Wood	20	80	0.07
5	Oakville	+	4.5	2500	2.5	NA	Wood	24	NA	NA
6	B.P. Refinery Canada Ltd. Oakville	-	NA	1789	2.5	NA	Concrete	23	NA	NA
7	St. Lawrence Starch Co. Ltd. Port Credit	-	NA	2400	2.0	4.6	Concrete	28	NA	NA
8	Toronto R.C. Harris	+	300	5385	10.75	10.75	Steel	40	1575	0.35
9	Toronto Westerly	-	120	NA	8	NA	Steel	37	250	0.89
		-	120	NA	8	NA	Steel	37	250	0.89
10	Pickering Twp.	-	0.6	1800	2.5	NA	Wood	17	NA	NA
11	Ajax	-	1.6	2100	3.0	NA	Concrete	33	NA	NA
12	Whitby	+	2.5	2900	3.0	NA	Concrete,wood	29	116	0.04
13	Oshawa	+	5.9	3030	2.5	3.0	Concrete,wood	38	36	0.5
14	Bowmanville	-	0.6	1830	2.0	NA	Wood	11	NA	NA
15	Port Hope	+	0.9	1720	1.4	NA	Unprotected	16	-	-
16	Cobourg	+	2.5	900	2.1	NA	Wood	16	36	0.13
17	Trenton	-	1.0	132	1.3	NA	NA	7	NA	NA
18	C.F.B. Trenton	-	NA	270	0.8	NA	Steel, wood	14	NA	NA

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APPENDIX II (Cont'd)

Supply Source Plant Identification Number	Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Intake Structure Construction	Water Depth (ft)	Ports Area (sq.ft)	Ports Average Velocity (fps)
	Lake Ontario (Cont'd)									
19	Belleville	+	4.3	1416	2.5	NA	Concrete	13.5	NA	NA
20	Deseronto	+	0.3	6	0.7	NA	Steel	4	NA	NA
21	Napanee	-	0.8	50	NA	NA	Concrete	3	NA	NA
22	Canadian Industries Ltd. Millhaven	-	NA	95	3	NA	Steel	95	24	NA
23	Kingston, City	-	9.0	1200	2.5	4.0	NA	55	72	0.23
	Point Pleasant	-	0.6	700	1.3	3.0	Concrete, steel	21	10	0.12
24	DuPont of Canada Ltd.	-	NA	2020	3.0	NA	Concrete	90	NA	NA
	Kingston	-	NA	1945	3.0	NA	Concrete	90	NA	NA
		-	NA	1922	1.6	NA	Concrete	90	NA	NA
	Lake Erie									
25	Crystal Beach	+	NA	1425	1.5	NA	Wood	12	NA	NA
26	Port Colborne	-	5.0	200	1.6	1.6	Wood	8	NA	NA
27	Dunn Twp.	+	1.5	1650	4.0	8.0	Wood	20	76	0.04
28	Jarvis	+	0.08	1200	1.0	NA	NA	15	NA	NA
29	Port Stanley	+	0.2	1960	1.0	NA	Concrete	15	NA	NA
30	West Lorne	+	0.2	1200	1.0	NA	Wood	17	NA	NA
31	Union Gas Co. Port Alma	+	0.9	1700	0.8	1.0	Unprotected	23	1.25	1.2
32	Wheatley	-	0.3	1400	2.0	NA	Wood	20	NA	NA
33	Allied Chemical Ltd. Amherstburg	-	1.8	25	NA	NA	NA	8.5	NA	NA
34	Port Rowan	-	0.07	650	1.0	NA	Unprotected	4	NA	NA
35	Lake Erie System	-	NA	4000	4.0	NA	Steel, wood	30	NA	NA
36	Harrow	-	0.25	1200	2.5	NA	Wood	21	NA	NA

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APPENDIX II (Cont'd)

Plant Number	Supply Source: Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Intake Structure: Construction	Water Depth (ft)	Ports: Area (sq.ft)	Ports: Average Velocity (fps)
	Lake St. Clair									
37	Windsor: New	-	24.2	1230	4.5	16	Wood	28.3	NA	NA
	: Old	+	NA	1630	4.0	5.0	Wood	27.0	NA	NA
	: Techumsch	-	2.2	350	3.0	NA	NA	21.0	NA	NA
38	Belle River	-	0.8	1850	1.3	NA	NA	9.0	NA	NA
	Lake Huron									
39	Petrolia	+	1.0	1200	1.3	NA	Steel	20	NA	NA
40	Goderich	+	0.8	1600	2.5	35	Wood	15	32	0.04
41	Lake Huron System	-	67	8300	6.0	6.0	Wood	26	415	0.30
42	Kincardine	-	0.4	2100	1.3	NA	Wood	14	39	0.02
43	Port Elgin	-	0.2	900	NA	NA	Concrete	15	NA	NA
44	Southampton	-	0.3	1200	2.0	NA	Concrete	6	NA	NA
	Georgian Bay									
45	Wiarton	-	0.7	75	1.2	NA	Wood	12	NA	NA
46	Owen Sound	-	2.6	2200	3.0	NA	Steel, wood	45	NA	NA
47	Meaford	-	1.1	870	2.5	NA	Wood	20	60	0.04
48	Collingwood	+	2.5	1060	1.6	NA	Wood	12	45	0.1
49	Midland	-	NA	840	1.5	3.0	Wood	40	NA	NA
50	Port McNicoll	-	0.24	450	1.0	NA	NA	18	NA	NA
51	Little Current	-	0.4	32	1.0	NA	NA	8	NA	NA
52	Thessalon	+	0.4	1100	2.0	NA	Wood	28	36	0.02

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APPENDIX II (Cont'd)

Supply Source								Intake Structure			
									Ports		
Plant Number	Identification Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Construction	Water Depth (ft)	Area (sq.ft)	Average Velocity (fps)
	Lake Superior									
53	Sault St. Marie	-	5.8	NA	2.0	2.0	Unprotected	8	3.2	3.4
54	Michipicoten	-	NA	500	2.0	NA	Wood	32	NA	NA
55	Kimberly Clark Ltd. Terrace Bay	+	NA	1600	14.5	NA	Unprotected	34	NA	NA
56	Port Arthur	-	NA	2339	2.0	2.0	Wood	28	NA	NA
	Lake Nipissing									
57	DuPont of Canada Ltd. North Bay	+	NA	1600	1.3	NA	NA	13	NA	NA
58	C.F.B. Hornell Heights	-	NA	400	2.0	4.0	Wood	80	NA	NA
59	North Bay	-	4	138	1.0x2	NA	Unprotected	6	NA	NA
60	Cache Bay	-	NA	400	0.9	0.9	Wood	8	NA	NA
61	Sturgeon Falls	+	0.6	360	1.5	NA	NA	9	NA	NA
	St. Lawrence River									
62	Gananoque	-	0.9	569	3.0	4.0	NA	32	NA	NA
63	Brockville	+	3.5	864	3.0	6.0	Concrete,Steel	30	8	0.93
64	Brockville Chemical Ltd. Maitland	-	NA	1625	1.5	1.5	Concrete	18.5	NA	NA
65	DuPont of Canada Ltd. Maitland	+	10.9	4	4	4	Unprotected	3	20	1.0
66	Prescott	+	0.7	400	2.0	NA	Wood	10	NA	NA
67	Canada Starch Co.Ltd. Cardinal	+	NA	370	2.0	NA	Wood	27	50	0.01
68	Iroquis	-	0.3	3000	1.3	NA	NA	28	NA	NA
69	Morrisburg	-	0.4	300	1.5	NA	Concrete	56	NA	NA
70	Cornwall	-	5.0	30	4.0	NA	Concrete	3	NA	NA

/continued

APPENDIX II (Cont'd)

Supply Source								Intake Structure			
										Ports	
Plant Number	Identification Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Construction	Water Depth (ft)	Area (sq.ft)	Average Velocity (fps)
	Ottawa River									
71	Ottawa	+	24	900	5.5	NA	Unprotected	24	NA	NA
72	Chats Falls Generating Stn. Fitzroy Harbour	+	NA	Headwall		-	Concrete	12	NA	NA
73	Arnprior	-	1.0	30	1.1	1.1	Concrete	9	NA	NA
74	A.E.C.L. Chalk River	-	NA	500	4.5	NA	NA	100	NA	NA
		-	NA	326	2.5	NA	Enamel Coated Steel	45	NA	NA
75	Deep River	-	0.84	300	2.5	2.5x2.5	Wood	18	NA	NA
76	Haileybury	-	0.5	1300	1.0	NA	NA	40	NA	NA
	Credit River									
77	Streetsville	-	0.6	16	7.5	NA	Wood	4	NA	NA
	Niagara River									
78	Niagara-on-the-Lake	+	0.35	90	0.8	NA	Wood	35	NA	NA
79	Niagara Falls	+	10	455	4.0	NA	Steel, wood	18	NA	NA
80	Fort Erie	+	1.25	250	1.6	1.6	NA	12	NA	NA
	Welland Canal									
81	Welland	+	5.3	260	8.0	8x8	Headwall	11.5	NA	NA
	St. Clair River									
82	Sarnia	+	8.9	360	4.0	NA	Wood	45	NA	NA

/continued

APPENDIX II (Cont'd)

Supply Source							Intake Structure			
									Ports	
Plant Number	Identification Installation	Ice Problems Experienced	Average Flow (MIGD)	Intake Length (ft)	Conduit Diam. (ft)	Inlet Diam. (ft)	Construction	Water Depth (ft)	Area (sq.ft)	Average Velocity (fps)
	Other Lakes and Rivers									
83	Alexandria	-	0.4	1500	1.2	NA	Wood	7	NA	NA
84	Bala	-	0.2	150	0.6	0.6	Concrete	7	NA	NA
85	Bancroft	-	0.07	NA	3.0	3.0	Steel	20	NA	NA
86	Bertie Twp.	-	1.3	1800	3.5	NA	Wood	15	NA	NA
87	Bracebridge	+	0.8	70	0.8	0.8x0.8	Headwell	15	NA	NA
88	Caleton Place	+	1.7	NA	1.5	1.5	Concrete, wood	10	NA	NA
89	Cobden	-	0.06	300	1.0	NA	Unprotected	12	NA	NA
90	Eganville	-	0.05	200	0.6	NA	Wood	6	NA	NA
91	Espanola	-	1.0	260	1.5	1.5	Wood	28	NA	NA
92	Freeman	-	0.2	145	0.8	NA	Concrete	15	NA	NA
93	Hearst	-	0.5	160	1.4	NA	Unprotected	2.5	NA	NA
94	Huntsville	-	0.4	11	NA	NA	Steel, wood	15	52	0.01
95	Abitibi Paper Co. Ltd Iroquois Falls	+	NA	15	2	NA	Concrete	4	NA	NA
96	Lakefield	-	0.1	45	0.2	NA	Unprotected	3	NA	NA
97	Lindsay	+	1.6	32	1.0	1.3	Unprotected	8	2.8	1.0
98	Marmora	-	0.09	300	0.8	0.8	Unprotected	6	0.6	0.3
99	C.F.B. Moosonee	-	NA	12	NA	NA	Concrete	6	NA	NA
100	Orillia	+	1.8	375	2.0	NA	NA	8	28	0.12
101	Perth	-	0.9	600	2.0	NA	Unprotected	5	NA	NA
102	Peterborough	+	6.4	70	2.5	2.5	Unprotected	9	15	0.8
103	Port Carling	-	NA	65	0.5	0.5	Wood	5	NA	NA
104	Smith Falls	-	2.0	1175	2.0	3.5	Wood	3	80	0.05
105	Sudbury	-	7.6	916	5.0	NA	NA	65	NA	NA
106	Timmins	-	7.0	215	Shore Intake		Concrete	6	12.5	1.04

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